Annual Project Summary
DEEP BOREHOLE TENSOR STRAIN MONITORING, NORTHERN CALIFORNIA

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II
seismology, geodesy, borehole geophysics

Project Objectives and Approach

This project provides field observations contributing to an understanding of fault processes associated with earthquakes along the San Andreas and Hayward faults. Continuous high precision and high resolution borehole tensor strain data provide an essential complement to long baseline interferometry studies (limited to sampling intervals of weeks), to GPS studies, and seismic characterisation of faults.

The project continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at San Juan Bautista in late 1983, expanded by three sites installed in the Parkfield area during December of 1986, by two sites deployed near the Hayward Fault in the San Francisco Bay region in 1992. Each instrument consists of a three component plane strain module operating at a strain sensitivity of 10^{-10} and support data logging systems. They provide data sampling at 30 minute intervals for transmission via satellite for permanent archive purposes. They provide unique continuous tensor strain data of high quality and sensitivity not achievable by any other instrumentation. These data form a critical complement to GPS and geodetic studies (see Figure 1) in assessing strain rates and consequent earthquake risk, as well as investigating fault processes associated with earthquake preparation and post-seismic relaxation.

Data are available from *http://www.cat.csiro.au/dem/msg/straincal/straincal.html*. Data are made available in near real time in the USGS Menlo Park computer system (***thecove:/home/mick/QUICKCHECK***). These data supplement long baseline survey data, and permit real time monitoring for short term strain phenomena.

The **immediate objectives** of the project are

- Maintenance of uphole system integrity at 5 Northern Californian sites, with repair or production of replacement uphole electronics if necessary.
- Manual preparation of raw instrument data for permanent archive.
- Analysis of continuous unique low frequency shear strain data (30 minute samples) and modelling studies based on the constraints of these data
- Regular reporting and real time alert response as part of the Parkfield Prediction experiment.
- Archive of processed data for access by the earthquake studies community, and provision of near-real time automatically processed data for inclusion in publicly accessible web pages linked to the USGS web datasets.

The project is carried out in parallel with maintenance of two further sites (Pinon Flat and San Gabriel mountains) in Southern California.

Investigations & Results

1. Parkfield 1997 Regional Event

In 1999, this project first identified a regional anomaly in the Parkfied area beginning in 1997. The anomaly appears to be continuing over the whole Parkfield region. The GTSM data is shown in figure 1. A previous anomaly beginning in 1993 and first reported in 1995 was subsequently confirmed by independent observations (Nadeau and McEvilly,1999 Langbein et al.,1999, and Gau et al.,2000).

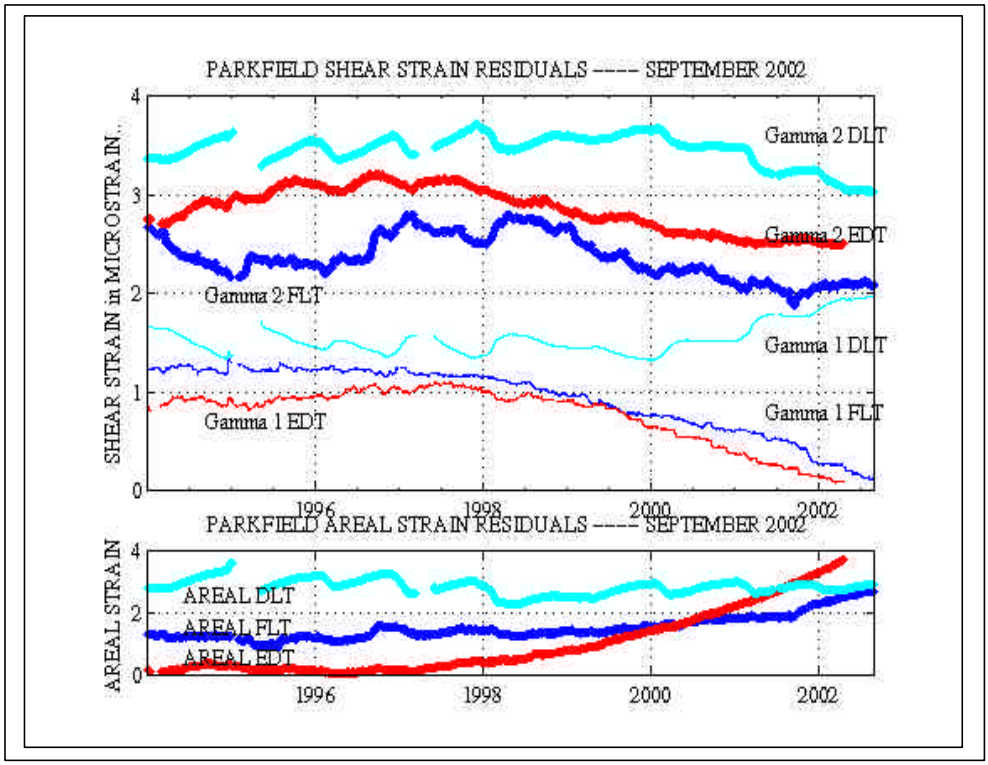

Figure 1: GTS data for Eades, Frolich and Donna Lee sites at Parkfield showing the long term anomaly beginning in late 1997.

Recently, the archived dilatometer data collected by USGS has been made available. These data have been subjected to the same type of processing as the tensor data, (ie removal by least squares fitting of borehole recovery effects). We have confirmed that the change in rate beginning in 1997 is also observed in some of the dilatometers. The data from three of the dilatometers associated with our instruments are shown below in figure 2.

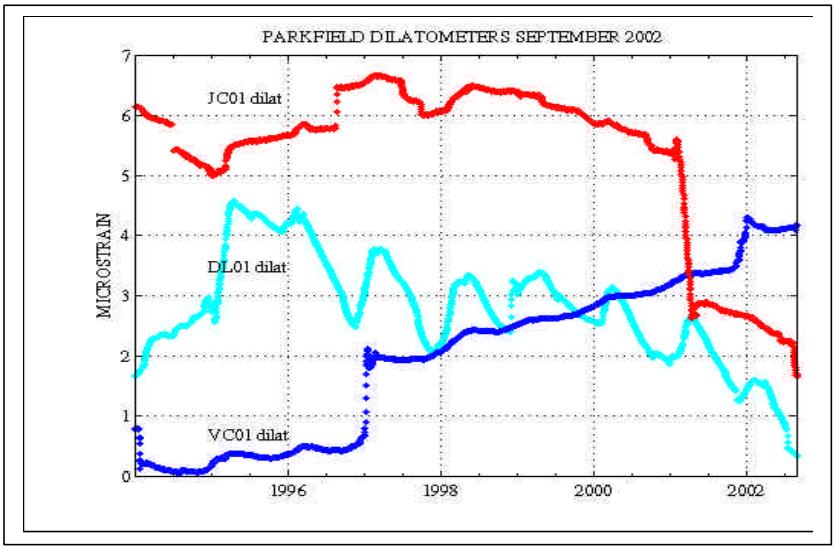

Figure 2. Dilatometer data for sites Joachin Canyon, DonaLee and Vinyard Canyon from the USGS archive. These data also indicate changes of strain rate beginning in 1997.

August 27, 2002, Parkfield Strain event.

An event occurred in the southern end of the Parkfield array occurred in August, 2002. This event was primarily detected on the near dilatometers. We evaluated the tensor data for the period, and found that there was no signal significantly above the noise at the time. The GTS data is shown in figure 3. Calculation of the expected strains from the dilatometer event at the distance of the tensor strainmseters would indicate that for the tensor sites, the step and rate change would be below detection level.

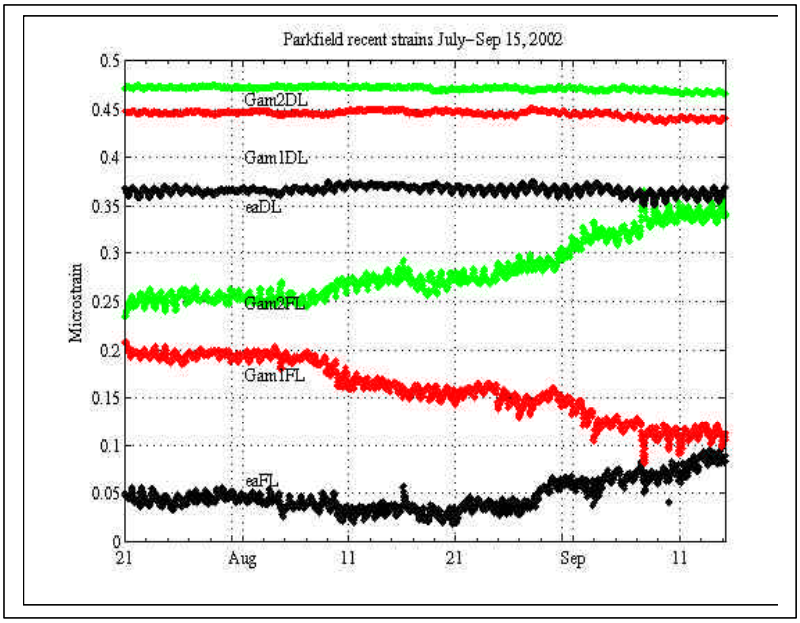

Figure 3*. Response at DonnaLee and Frolich near the August 27 event. The rate change in both shear strains but not in the areal strain rate at the Frolich site in early August may not be associated with the southern Parkfield activity.*

Creep-Strain Events

A catalogue of creep strain events of the kind identified by these instruments in the San Juan Bautista area is being developed for the Parkfield area. An example of a recent event beginning with rate changes on the 11th and 26th April for the gamma1 component at Frolich is shown in **figure 4**. The creep meter response to the second event may be contaminated by the rainfall on April 27.

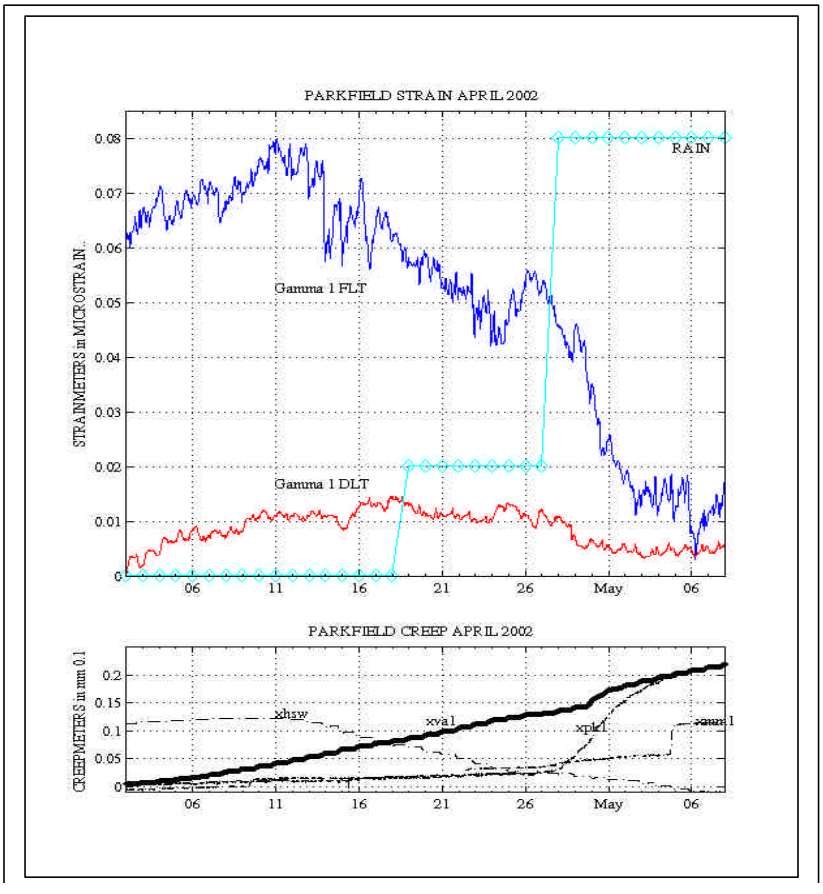

Figure 4.

Parkfield strain rate change associated with a creep event on march 11,2002.

Gilroy event, May 14, 2002.

We continue to observe coseismic offsets associated with earthquakes in the vicinity of the strainmeter sites. **Figure 5** illustrates a recent offset from the Gilroy earthquake of May14 2002, which occurred 15km to the north on the Sargent fault. The strain offsets in this event were 39 ne (areal), -45 ne (Gamma 1) and –66 ne (Gamma2). These are very close to the offsets modelled for a strike slip event of magnitude 4.9 on the Sargent fault (30 ne, -35 ne and –60 ne respectively). The expected offsets from an earthquake with fault parameters as determined by the Berkeley moment tensor solution catalog are also close to the observed values (33 ne, -46 ne and -54 ne respectively).

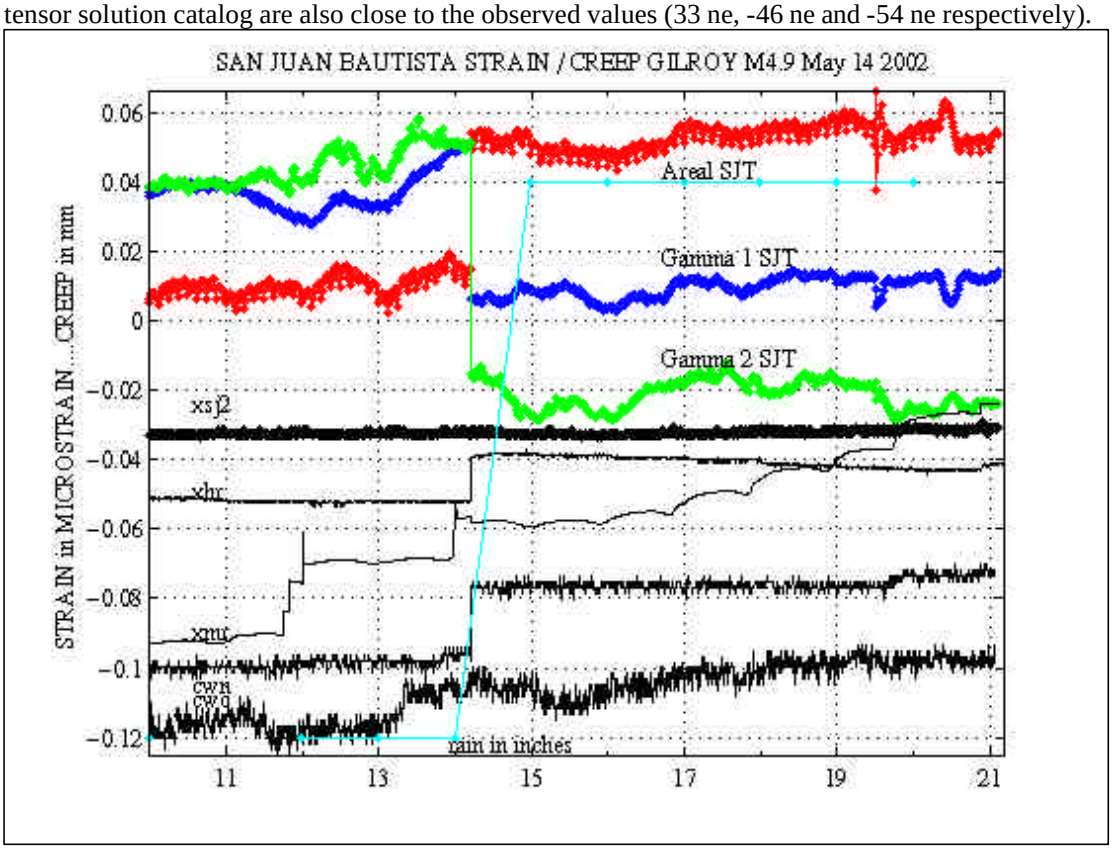

Figure 5 *Strain offset caused by the Gilroy earthquake of May 14, 2002.*

The strain model derived for the Berkeley solution for the event is shown in figure 6 below. The strain data are consistent with the solution.

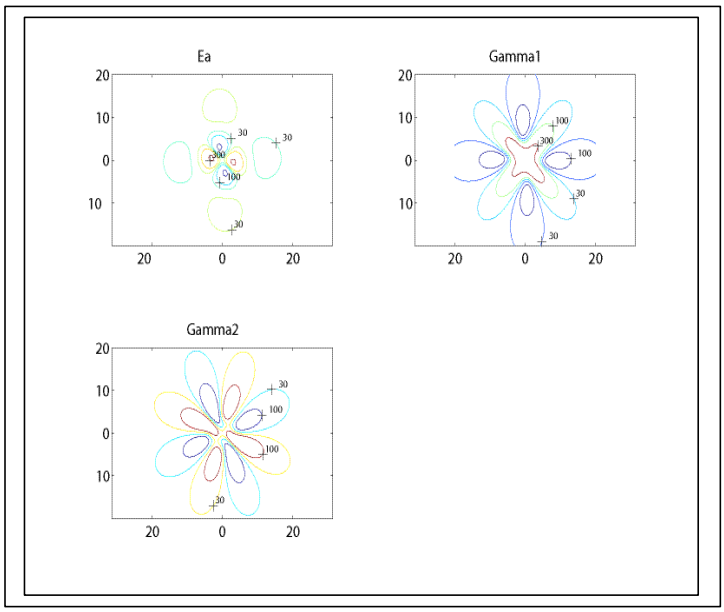

Figure 6 *Predicted strain field for the Gilroy event based on the Berkeley solution.*

Continued Creep strain events at SJT.

A further creep strain event bringing the number in catalog to 36 occurred in the San Juan area on June 6, 2002. The event is typical with the strain event occurring several days before the surface creep occurred. The event, which is the only one which occurred in this reporting period is shown below (figure 7).

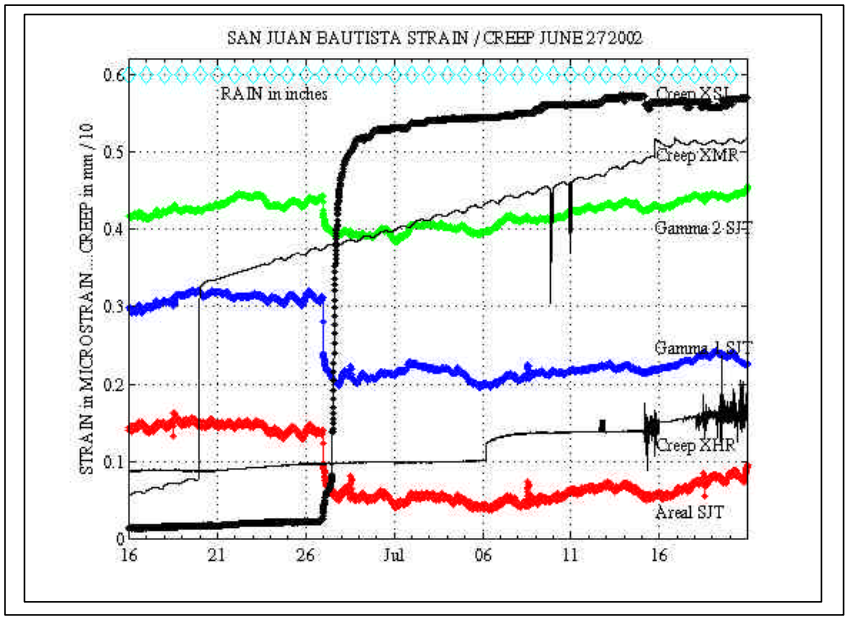

Figure 7. *A new creep strain event at San Juan bautista*

A non associated strain event at San Juan Bautista occurred in June, 2002. The event showed dominantly on the gamma one component, and was not accompanied by any creep on the nearby creep meters, confirming that the source region was different from those in our current creep strain catalog. The event was followed ten days later by a sequence of creep events over the region. The data is shown in figure 8. Delays this large are unusual for the region, though they are common in the Parkfield area.

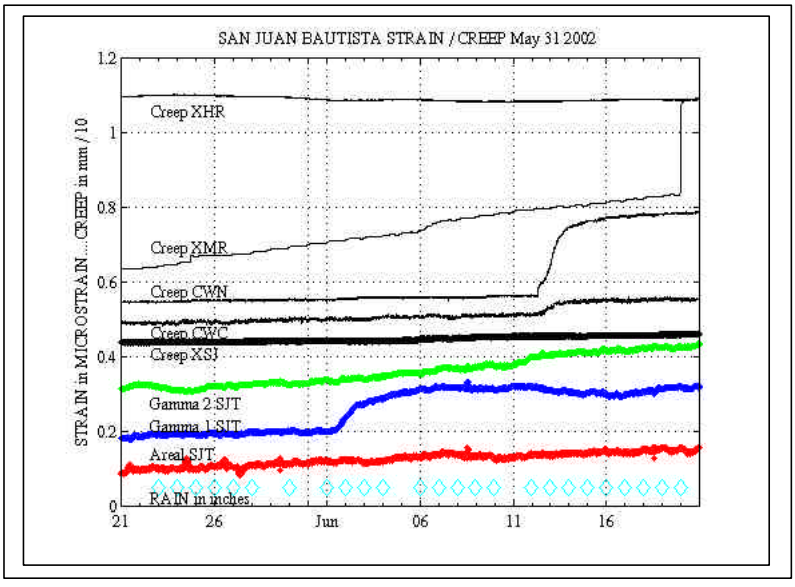

Figure 8. *Atypical Creep strain association for the San Juan Bautista area. The event occurred dominantly on gamma 1, and the only creep response was delayed many days*

Data Availability

Archived strain data from the Californian sites are stored in both raw component form, and as processed areal and shear strains. A regularly updated archive of data has been maintained in the USGS Menlo Park computer system since 1988. This data is stored in binary files with appended header information (USGS "*bottle*" format).

Home page for access to data plots from all borehole tensor strain instruments is http://www.cat.csiro.au/dem/msg/straincal/straincal.html. ***This page also includes facilities for download of raw or processed data from our CSIRO archive***.

Automatically processed near-realtime data is available in *thecove:/home/mick/QUICKCHECK* for users with access to USGS plotting software "*xqp*", and via the USGS crustal deformation web pages in graphical form.

Scientists requiring other access to the archived data should contact Dr. M.T. Gladwin (+617 3212 4562).

Publications

Recent Publications

Gwyther,R.L , Gladwin,M.T, & Hart,R.H.G. &M.Mee Focussed Study of Aseismic Fault Processes, *Workshop Abstracts, Earthscope Workshop: Making and Breaking a Continent, October 2001. p 157-160, 2001*

Gwyther R.L., M.T. Gladwin, R.H. Hart & M.Mee Aseismic stress transfer between shallow and medium depths in transition zones of the San Andreas Fault.. *EOS. (Trans. Am. Geo. Un.)*, 2001.

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Gwyther, R.L., C.H. Thurber, M.T.Gladwin &M. Mee Seismic and Aseismic Observations of the 12th August 1998 San Juan Bautista, California M 5.3 earthquake, *Proc. 3rd Conf. on Tectonic Problems of the San Andreas Fault*, 2000

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Gladwin,M.T., Gwyther,R.L., & Hart,R.H.G., Addition of Strain to Targeted GPS Clusters-New Issues for Large Scale Borehole Strainmeter Arrays, *Proc. 2nd Plate Boundary Observatory Workshop*,1.17a-1.17e, *2000*

Langbein, J., Gladwin, M.T., & Gwyther,R.L., Extension of the Parkfield deformation array,*Proc. 2nd Plate Boundary Observatory Workshop*,2.45-2.49,2000

Thurber,C., Gladwin,M.T., Rubin,A., & DeMets,D.C., Focussed Observation of the San Andreas/Calaveras Fault intersection in the region of San Juan Bautista, California, *Proc. 2nd Plate Boundary Observatory Workshop*,2.75-2.79, 2000

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Langbein, J., Roeloffs,E., Gladwin,M.T.,& Gwyther R.L., Creepmeters on the San Andreas Fault System between San Francisco Bay and Parkfield, *Proc. 2nd Plate Boundary Observatory Workshop*, 2.40-2.44, 2000

Selected Previous Journal Publications

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Gwyther R.L., M.T. Gladwin and R.H.G. Hart Anomalous Shear Strain at Parkfield During 1993-94 *Geophys. Res. Lett. V 23 (18)* p 2425-2428, 1996

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Gladwin, M.T., Gwyther, R.L., Hart, R.H.G. and Breckenridge K.(1993) Measurements of the strain field associated with episodic creep events on the San Andreas fault at San Juan Bautista, California (1994*). J. Geophys. Res*. Vol 99 (B3), 4559-4565.

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Gwyther R.L., Gladwin M.T. and Hart R.H.G. (1992) A Shear Strain Anomaly Following the Loma Prieta Earthquake. *Nature* Vol 356 No.6365 pp 142-144.

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Johnston, M. J. S., Linde, A.T., Gladwin, M.T., and Borcherdt, R.D. Fault Failure with Moderate Earthquakes. *Tectonophysics*. 144, 189-206, 1987. .

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Non-Technical Summary

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This project provides field observations of horizontal strain changes over timescales from minutes to years, critical to an understanding of fault processes associated with earthquakes along the San Andreas and Hayward fault systems. The project continues a program of maintenance and analysis of deep borehole tensor strain instrumentation initiated at San Juan Bautista and Pinon Flat Observatory in late 1983. Three further instruments were deployed near Parkfield in central California in 1986, and two instruments were deployed near the Hayward fault in 1992. A series of episodic strain events associated with surface creep events have been observed at Parkfield, similar to those previously reported at San Juan Bautista. A regional strain anomaly at Parkfield first reported in 1994 has been confirmed by other instrument types, and a second event beginning in 1997 is still continuing. The occurrence of episodic events is directly related to longer term changes in strain rate at these sites, and suggests processes for stress transfer from medium to shallow depths of the fault. This project runs in parallel with a maintenance project covering two further instruments in Southern California.